

## P-25: Subatomic Physics

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### Introduction

The Subatomic Physics Group (P-25) is primarily engaged in research into nuclear and particle physics. There is also a strong and growing effort to turn the group skills and capabilities to applied programs such as proton radiography. The group currently is conducting research and developing new programs at Los Alamos and at other laboratories, such as Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (FNAL or Fermilab), and the European Center for Nuclear Research (CERN). The people and programs in the Subatomic Physics Group were recently rated highly in a nationwide review of the DOE Nuclear Physics Program. Some highlights of the group's activities and future directions follow.

### Pion Physics

The neutral meson spectrometer (NMS) had its final LANSCE (Los Alamos Neutron Science Center) run of 3.5 months before it was shipped to BNL, where it will be used in another experiment. We are now analyzing the new data as well as data from previous runs, with emphasis on the  $^{32}\text{S}(\pi^-, \pi^0)$  reaction. The report of this work will be available by late 1997. We are rewriting the NMS data analyzer program to improve this and other analyses. That work will be applicable to the BNL experiment.

### Hypernuclear Physics: Experiment E907 at the Alternating-Gradient Synchrotron (AGS) at BNL

We led the effort to propose this new hypernuclear experiment at the AGS using the LANSCE NMS to measure the  $(K^-, \pi^0)$  reaction. This experiment will demonstrate the feasibility of using the  $(K^-, \pi^0)$  reaction as a novel tool to produce  $\Lambda$ -hypernuclei with resolution significantly better than the existing  $(K^-, \pi^-)$  and  $(K^+, \pi^+)$  experiments and will measure the  $\Lambda$ -hypernuclear  $\pi^0$  weak decay modes that have never been studied before. The proposal was approved by the AGS Program Advisory Council in late 1994. The NMS and associated equipment were moved from LANSCE to the AGS in December 1995, and the first test run was completed in May 1996. The LANL group will assume the major responsibilities for the NMS operation and for the physics direction in this experiment.

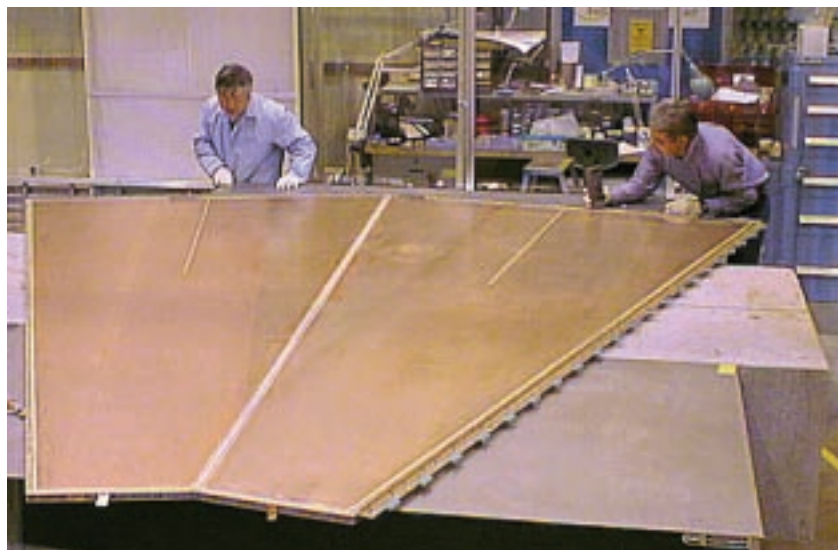
### Quark-Gluon Physics

This has been a highly visible and productive program at Fermilab. Our group was the first to exploit high-energy hadronic processes to explore the quark structure of nuclei. We are investigating the nuclear dependence of lepton-pair production with proton beams to understand how the quark and gluon structure in nuclei differs from that in free nucleons. During 1995–1996 we made substantial progress in the construction and refurbishing of the Fermilab Meson-East spectrometer, where E866 began taking data in July 1996. That experiment will search for deviations in the anti-up and anti-down quark distributions in the proton to provide insight into hadronic and partonic descriptions of the nucleonic sea.

We also continued major analysis efforts on past experiments E772 and E789. We developed Monte Carlo and analysis software that will enable the extraction of cross sections from 1.5 million Drell-Yan and Upsilon production events from the copper beam dump of E772. We completed the analysis (and publication) of the first  $B$ -meson cross-section data for 800-GeV proton-nucleus interactions and published the nuclear dependence of  $J/\psi$  production in the negative  $x$ -Feynman region.

### PHENIX Spin Program

The highly successful Los Alamos/RIKEN (Institute for Physical and Chemical Research—Tokyo [Wako], Japan) collaboration was the culmination of two years of work and resulted in the final specification of the RIKEN contribution to the spin-structure function program of the PHENIX detector. RIKEN funding will purchase the PHENIX south-arm magnet plus associated muon tracking and identification systems. This contribution greatly enhances the high-mass dimuon acceptance of the PHENIX detector (Fig. I-11) and permits a large menu of unique spin-structure function experiments to be carried out. Equally important, the muon upgrade will add substantially to the physics reach of the relativistic heavy-ion program.



*Fig. I-11. P-25 technicians building part of the PHENIX detector.*

### **Electroweak Physics: LSND**

The Liquid Scintillator Neutrino Detector (LSND), commissioned at LANSCE in 1993, has led to published papers describing the detector and source systems and the full decay-at-rest analysis of all data taken up to December 1995. The LSND paper "Evidence for Neutrino Oscillations from Muon Decay at Rest" has been published. A first-pass analysis on decay-in-flight data gave encouraging results. That analysis is more difficult than decay at rest since the signal properties are less elaborate. In addition, the magnitude of the excess is likely to have a strong impact on our estimate of  $\Delta m^2$  and so demands the greatest care. That analysis should be complete during 1997, including papers describing the analysis.

### **BOONE (Booster Neutrino Experiment)**

The definitive experimental establishment of nonzero neutrino mass will have far-ranging impact into other fields such as astrophysics; there is a strong need for experiments to follow up our successes with LSND. We have studied the possible BOONE detector and source systems and explored the level of electron neutrinos that can be expected from the beam and background at Fermilab. The detector seems to be quite adequate for both  $\Delta m^2$  scenarios suggested by LSND. The detector methodology could follow the LSND method because of performance improvements that the LSND analysis has engendered.

### **MEGA**

The apparent conservation of muon number remains a central problem of weak-interaction physics. Searching for processes that violate muon-number conservation will give insight into the possible extensions of the minimal standard model of weak interactions. MEGA (muon decays into an electron and a gamma ray) was designed to make such a search at the Los Alamos Meson Physics Facility (LAMPF), now known as LANSCE. The final year of taking data for this experiment was 1995–1996. The combined data from the summers of 1993–1995 should yield a statistical precision that improves the current world sensitivity to this process by a factor of 70 to roughly  $7 \times 10^{-13}$ . The MEGA collaboration made substantial strides in the development of algorithms to extract the results. The three major components of the analysis needed are reconstruction of the kinematic properties of the photon, kinematic properties of the positron, and their relative timing. The photon analysis is nearly complete, and the other two have reached an advanced stage.

## RHO

The MEGA positron spectrometer was used to measure the Michel parameter  $\rho$ . The parameter governs the shape of the polarization-independent part of the energy spectrum for positrons emitted in normal muon decay. The standard model predicts  $\rho$  to be 0.75; it is currently known to be within 0.3% agreement with that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. Collected data will enable a statistical precision that will allow the value of  $\rho$  to be measured to 0.05%, but the systematic errors are being evaluated. Such a precision will allow the checking of the reported deviations from the standard model in neutron decay. The analysis should be complete by the end of 1997.

## Measurements of Beta Asymmetry and Atomic Parity Nonconservation

A key step in undertaking the measurements of beta asymmetry and parity nonconservation is the efficient trapping of selected radioactive species. This is done using a magneto-optical trap. Using a high-intensity laser, we have developed one of the world's largest traps, which can trap up to  $4 \times 10^{10}$  atoms of stable cesium. We are further improving the trapping efficiency by coating the inside of the glass trapping cell with a special nonstick coating of octadecyltrichlorosilane (OTS) and by using two lasers operating at slightly different frequencies to reduce light-assisted losses, which become limiting at high beam intensities.

## Theory

The Subatomic Physics Group has a small theory component. We are developing a theory for connecting hadron properties in free space. We have also explored phenomenological approaches that can be used to determine (from data) masses and coupling constants for higher-mass resonances in nuclei. We are developing a theory for connecting mean-square matrix elements of the parity-violating interaction, measured by TRIPLE in compound nuclear resonances, to the underlying parity-violating force, exploiting the chaotic properties of the compound nucleus. We have been looking at the reaction theory of pion scattering from nuclei with an eye toward simplifying the description of specific reactions so that these reactions can be more easily used for specific purposes, such as evaluating hadron transport in nuclear collisions and interpreting the results of dibaryon resonance searches.

One group member investigated the phenomenon of neutrino oscillations within a three-state mixing model and found that all reported neutrino-oscillation data are consistent with a mass-mixing-angle analysis in terms of three neutrinos. His "Gravitationally Induced Neutrino-Oscillation Phases" is the First Award Essay for 1996 by the Gravity Research Foundation.

Participants at a relativistic heavy-ion meeting held during the summer of 1995 determined that essentially all relativistic heavy-ion transport event generators are incapable of reproducing the pion production data taken at LANSCE. We are investigating the reasons for this; the answer could have a significant impact on our heavy-ion and PHENIX experimental programs.

### **Applied Programs: Proton Radiography**

The decision to forgo underground nuclear testing and to restrict the nuclear stockpile to an increasingly smaller number of weapons has forced DOE and its laboratories to rethink their role in stockpile stewardship. Much of this reassessment has been embodied in the philosophy of science-based rather than test-based stockpile stewardship.

Proton radiography offers several advantages over conventional x-ray techniques for radiographing thick, dense, dynamic systems. These advantages are (1) high penetrating power, (2) high detection efficiency, (3) very small scattered background, (4) the lack of a need for a conversion target and the consequent phase space broadening of the beam, (5) inherent multipulse capability, and (6) the ability to tolerate large stand-off distances from the test object and containment vessel for both the incoming and outgoing beam. Additionally, proton radiography provides the unique possibility of measuring both the density and the material composition of a test object with a pulsed system.

Protons interact with matter through both the long-range Coulomb force and the short-range strong interaction. Focusing protons using a magnetic lens (Fig. I-12) both allows the magnitude and Z-dependence of the interaction to be changed simply by looking at an object through different angular apertures and leads to the capability of assessing material composition. Multiple images can be made on a single axis by using multiple detectors, lenses, and irises.

P-25 leads this effort, together with a strong cross-divisional team including P, X, DX, ESA, T, and LANSCE Divisions.

### Education and Outreach

P-25 continues to be active in education and outreach activities. We are formal members of three education programs run by the Laboratory. Group members visited every teacher and school in the TOPS (Teacher Opportunities to Promote Science) and TOPS Mentor programs at least once in 1995–1996; conducted regional meetings for TOPS teachers, TOPS Mentors, and TOPS alumni; and led several workshops in Los Alamos and Albuquerque. During a recent workshop, TOPS mentors built (from scratch) a simple lightning detector designed by physicists from NIS-1 and P-25. We were also active in the PRISM (Preservice Institute for Science and Math) program, guiding its students through a comparison of the transmission qualities of various brands of sunglasses.

*Fig. I-12. Schematic diagram of the lenses and collimator on the dynamic proton-radiography beamline.*

